# Advanced Operating Systems (CS 202)

# Extensible Operating Systems

# Our first paper discussion

- Research is a conversation advanced by different papers
  - We'll try to get a sense of the conversation
    - …which spans multiple papers
    - …typically read one or two, and I will fill in other threads
- Some conversations are old classics ☺
  - To learn something useful, we need to think about how they inform the present

# Operating System Organization

- The bigger conversation…
- In the 70s and 80s, OS design started emerging as a discipline

- How should the OS be structured?
  - Why does it matter? What can be accomplished by a good/bad structure?

- For time sharing, its clear we need a separate OS and User space
  - Do we need further structure?

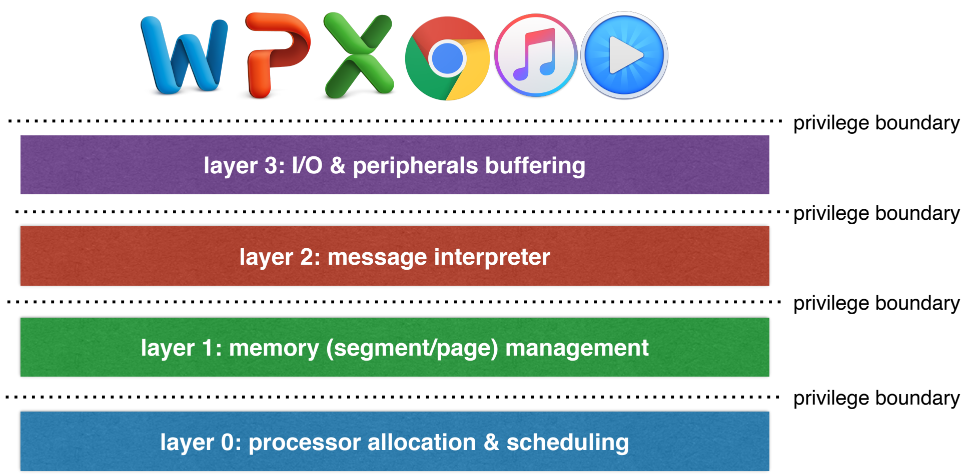
# Why is the structure of an OS important?

- Protection
  - User from user and system from user
- Performance
  - Does the structure facilitate good performance?
- Flexibility/Extensibility
  - Can we adapt the OS to the application
- Scalability
  - Performance goes up with more resources
- Agility
  - Adapt to application needs and resources
- Responsiveness
  - How quickly it reacts to external events
- Can it meet these requirements?

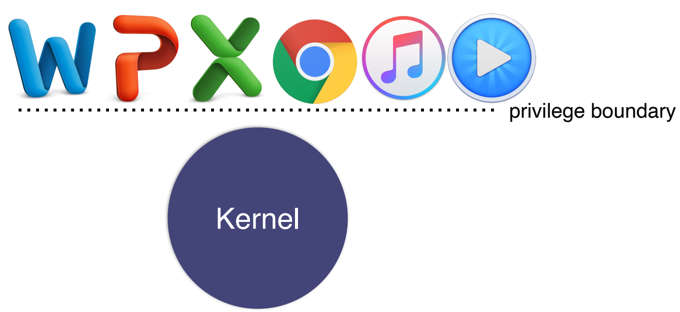
# An earlier conversation

## THE v.s. Hydra

### THE




### Hydra

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# Extensibility

- What do we mean by extensibility?
  - Flexible to add new features/functionalities
  - Good efficiency
  - Good security

- Can you give a few examples?
  - Device drivers
  - Browser plugins/extensions

# Extensibility context

- Traditional OS provide standard
  - Set of abstractions
    - Processes, threads, VM, Files, IPC
    - Reachable through syscalls
  - Resource allocation and management
  - Protection and security
- Industry complaining of OS large overheads
  - Researchers were doing customized extensions
  - Research community started asking how to provide customization?
    - Flux OS toolkit

# Is extensibility really important?

- What are some of arguments in the paper?
  - OS does not perform well for specific applications
    - End to end argument in system design
- What specific examples of applications do they list?
- Is it an implementation or abstraction issue?
    - Both? Abstractions overly general, and implementations are fixed
    - Protection and management interfere with performance and flexibility

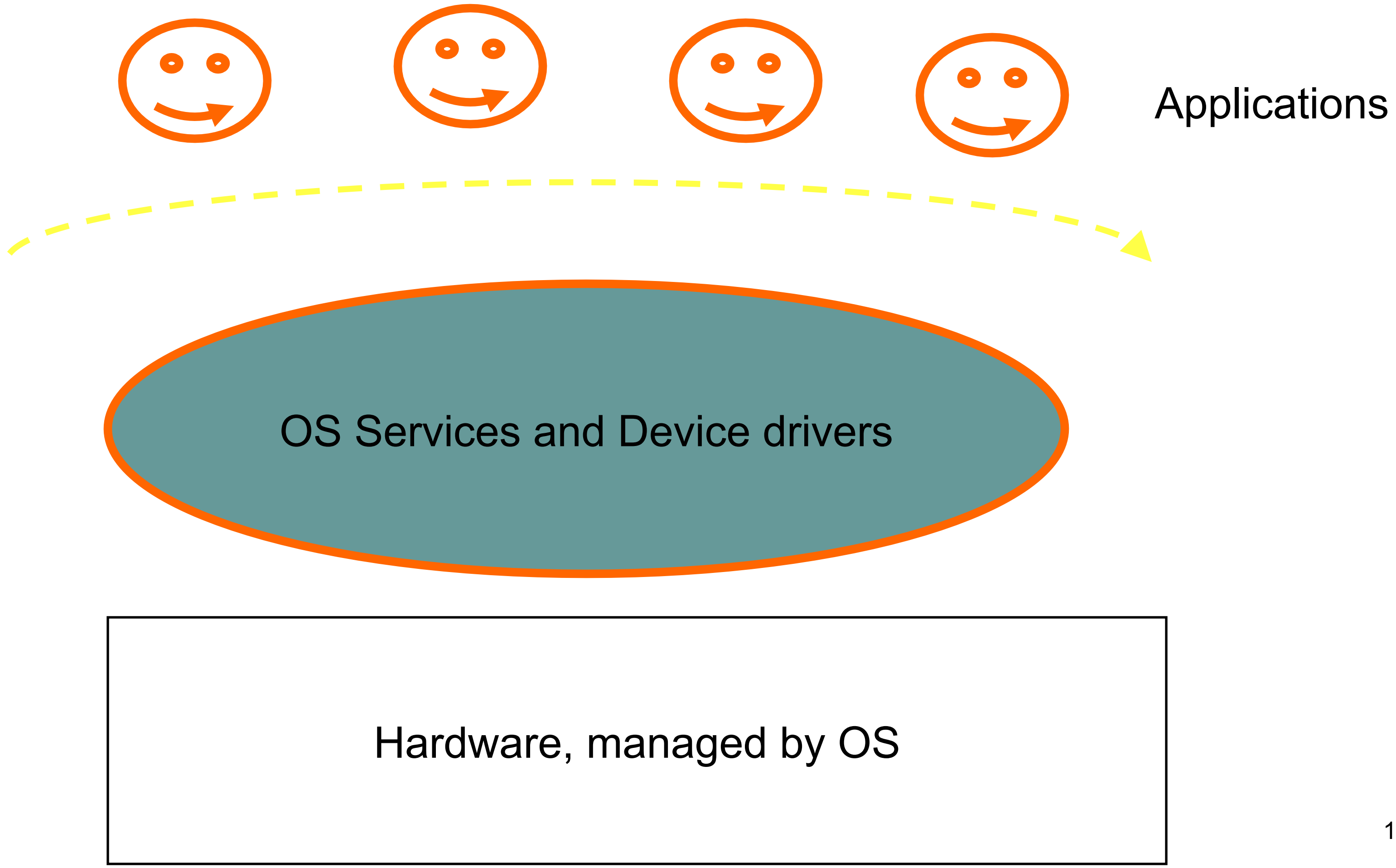
# How expensive are border crossings?

- Procedure call: save some general-purpose registers and jump
- Mode switch:
  - Trap or call gate overhead
    - Nowadays syscall/sysreturn
  - Switch to kernel stack
  - Switch some segment registers
  - 100s of ns
- Context switch?
  - Change address space
  - This could be expensive; flush TLB, …
  - Few microsecs

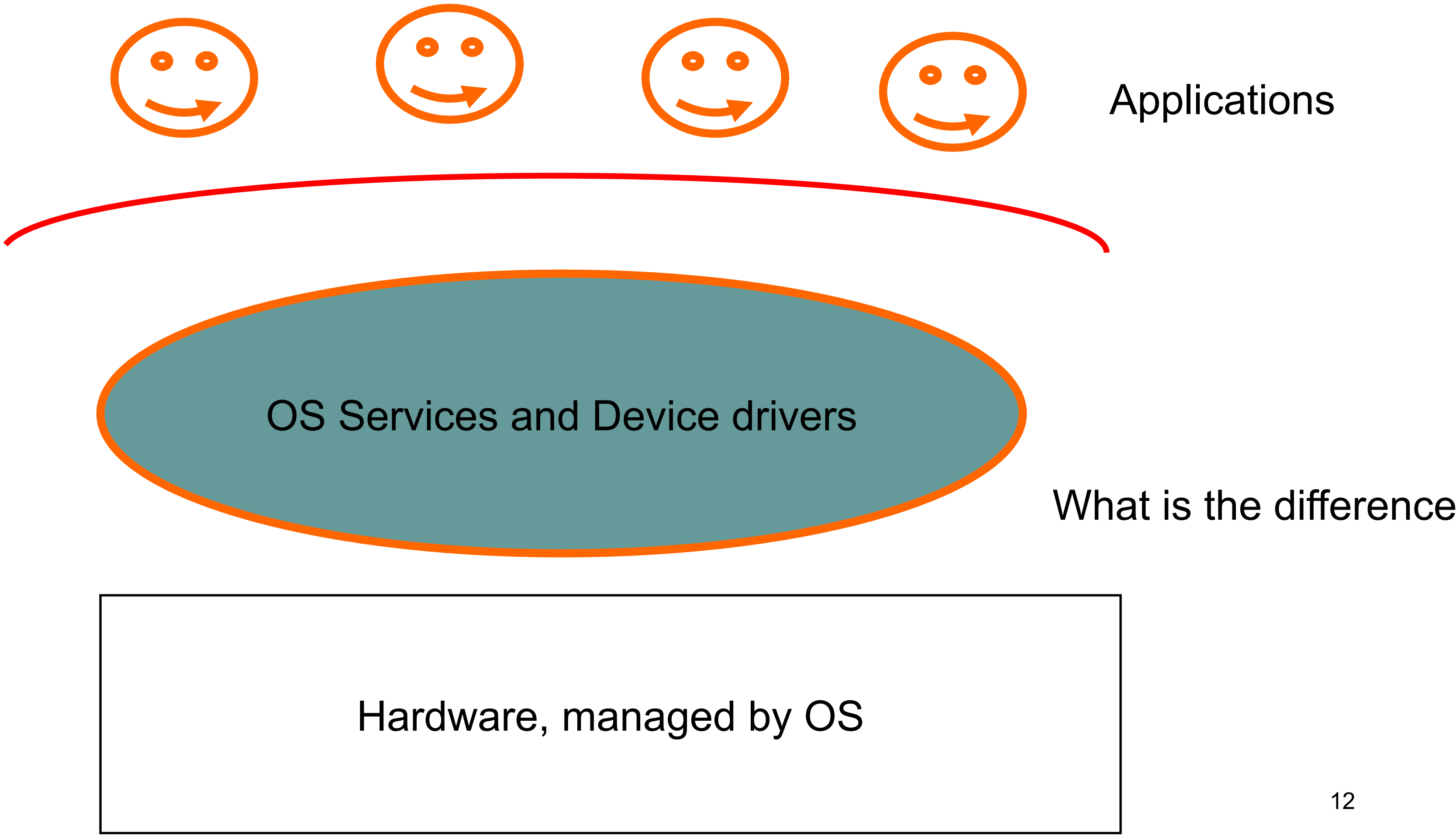
# OS design models

- Library OS
- Monolithic Kernel
- Micro Kernel

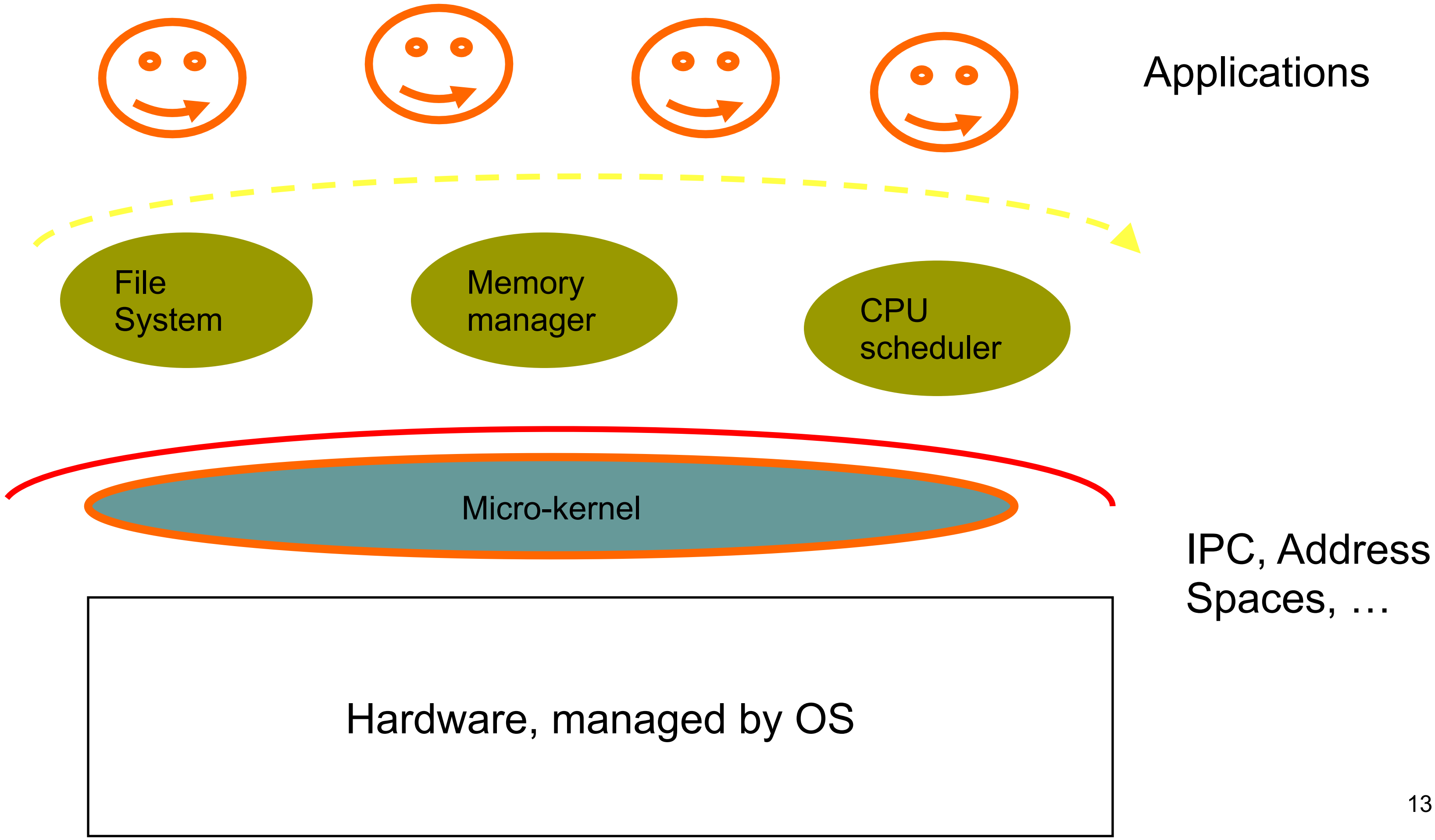
# OS as library (DOS-like)



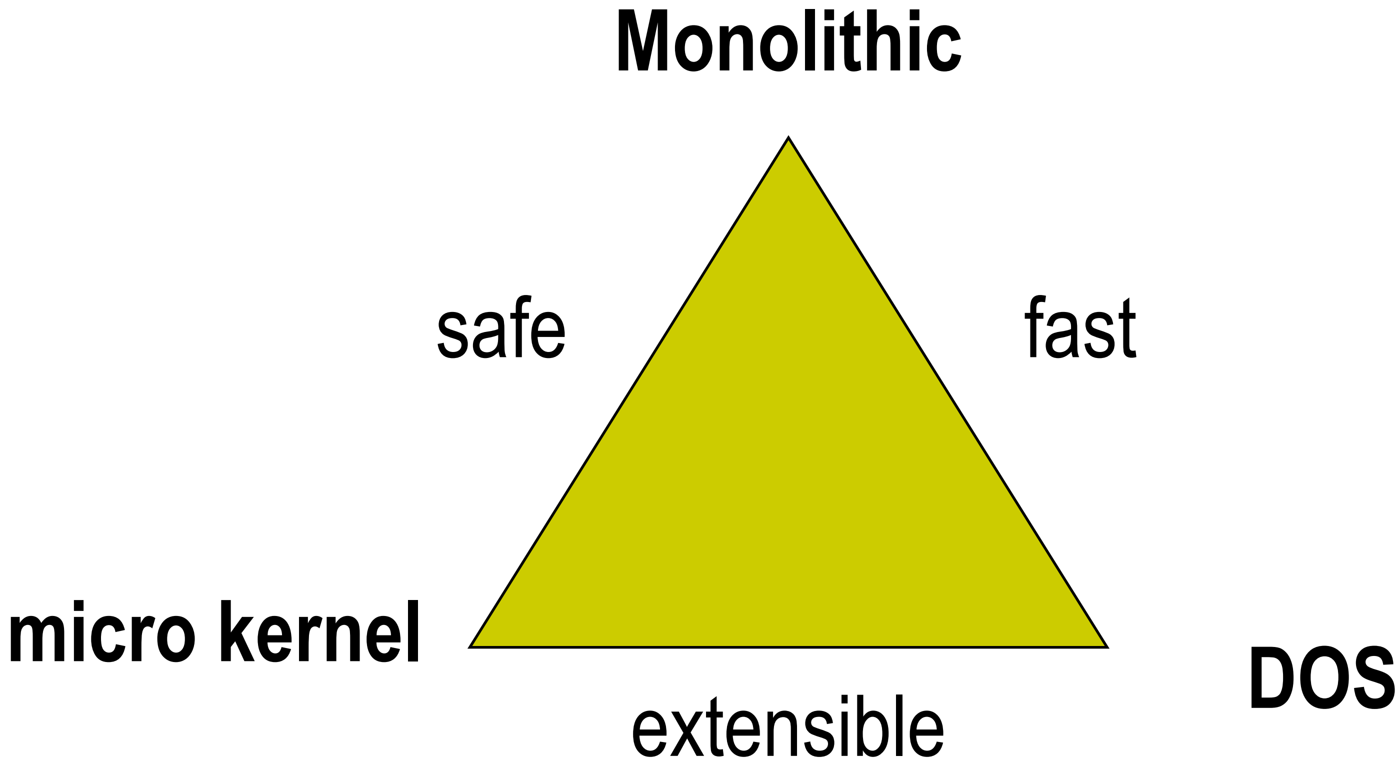
# Monolithic Kernel



# Micro-kernel



# More simply



# Summary

- DOS-like structure:
  - good performance and extensibility
  - Bad protection
- Monolithic kernels:
  - Good performance and protection
  - Bad extensibility
- Microkernels
  - Very good protection
  - Good extensibility
  - Bad performance!

# Poll: What properties should an extensible OS have?

# What should an extensible OS do?

- It should be thin, like a micro-kernel
  - Only mechanisms (or even less?)
  - no policies; they are defined by extensions
- Fast access to resources, like DOS
  - Eliminate border crossings
- Flexibility without sacrificing protection or performance
- Basically, fast, protected and flexible

# What had been done before?

- Hydra (Wulf ’81)
  - Kernel mechanisms for resource allocation
  - Capability based resource access
    - This was expensive as implemented
  - Resource management as coarse grained objects to reduce boarder crossings
- Microkernel (e.g., Mach in the 90s)
  - Focus on extensibility and portability
  - Portability hurt performance
  - Gave a bad rep to microkernels

# Existing Approaches

- Directly insert code modules
  - E.g., Loadable kernel module
  - Good efficiency
  - Bad security
- Put into a new process
  - E.g., User-mode driver (e.g., FUSE)
  - E.g., Microsoft puts browser plugin into a new process
  - Good security
  - Bad efficiency (context switch/mode switch)

# Spin Approach to extensibility

- Co-location of kernel and extension
  - Avoid border crossings
  - But what about protection?
- Language/compiler forced protection
  - Strongly typed language
    - Protection by compiler and run-time
    - Cannot cheat using pointers
  - Logical protection domains
    - No longer rely on hardware address spaces to enforce protection – no boarder crossings
- Dynamic call binding for extensibility

# Logical protection domains

- Modula-3 safety and encapsulation mechanisms
  - Type safety, automatic storage management
  - Objects, threads, exceptions and generic interfaces
- Fine-grained protection of objects using capabilities. An object can be:
  - Hardware resources (e.g., page frames)
  - Interfaces (e.g., page allocation module)
  - Collection of interfaces (e.g., full VM)
- Capabilities are language supported pointers

# Logical protection domains -- mechanisms

- Create:
  - Initialize with obje
- Resolve:
  - Names are resolv
    - Once resolved, a
- Combine
  - To create an aggr

```
INTERFACE Domain;

TYPE T <: REFANY;   (* Domain.T is opaque *)

PROCEDURE Create(coff:CoffFile.T):T;
(* Returns a domain created from the specified object
   file (''coff'' is a standard object file format). *)

PROCEDURE CreateFromModule():T;
(* Create a domain containing interfaces defined by the
   calling module.  This function allows modules to
   name and export themselves at runtime. *)

PROCEDURE Resolve(source,target: T);
(* Resolve any undefined symbols in the target domain
   against any exported symbols from the source.*)

PROCEDURE Combine(d1, d2: T):T;
(* Create a new aggregate domain that exports the
   interfaces of the given domains. *)

END Domain.
```

- This is the key to spin – protection, extensibility and performance

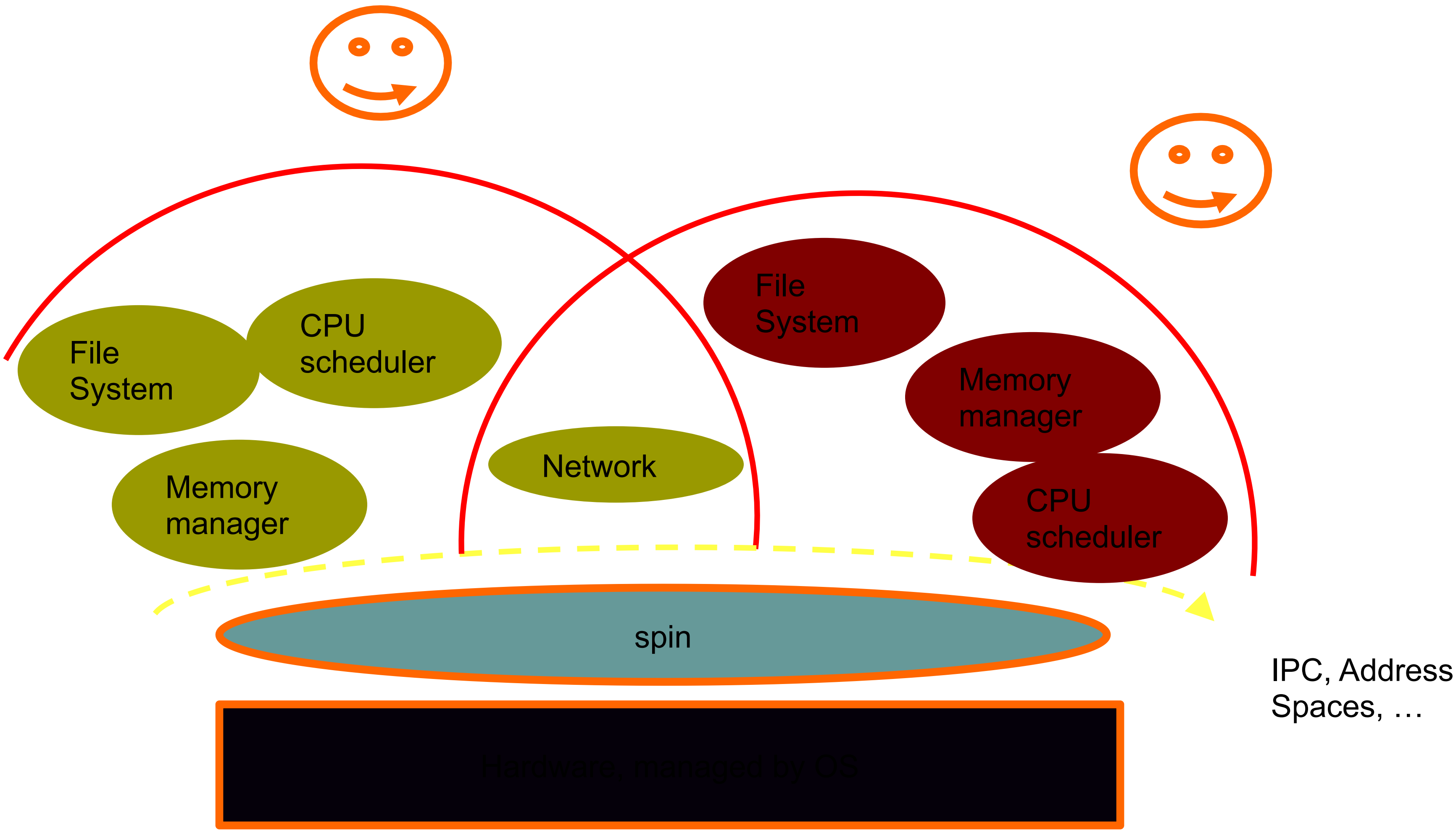
# Protection Model (I)

- All kernel resources are referenced by *capabilities* [tickets]
- SPIN implements capabilities directly through the use of pointers
- Compiler prevents pointers to be forged or dereferenced in a way inconsistent with its type at *compile time*:
  - No run time overhead for using a pointer

# Protection Model (II)

- A pointer can be passed to a user-level application through an *externalized reference:*
  - Index into a per-application table of safe references to kernel data structures
  - Similar to file descriptors, or socket descriptors in unix
- Protection domains define the set of names accessible to a given execution context

# Spin


File
System
CPU
scheduler
Memory
manager
Network
File
System
Memory
manager
CPU
scheduler
spin
IPC, Address
Spaces, …

# Spin Mechanisms for Events

- Spin extension model is based on events and handlers
  - Which provide for communication between the base and the extensions
- Events are routed by the Spin Dispatcher to handlers
  - Handlers are typically extension code called as a procedure by the dispatcher
  - One-to-one, one-to-many or many-to-one
    - All handlers registered to an event are invoked
      - Guards may be used to control which handler is used

# Event example

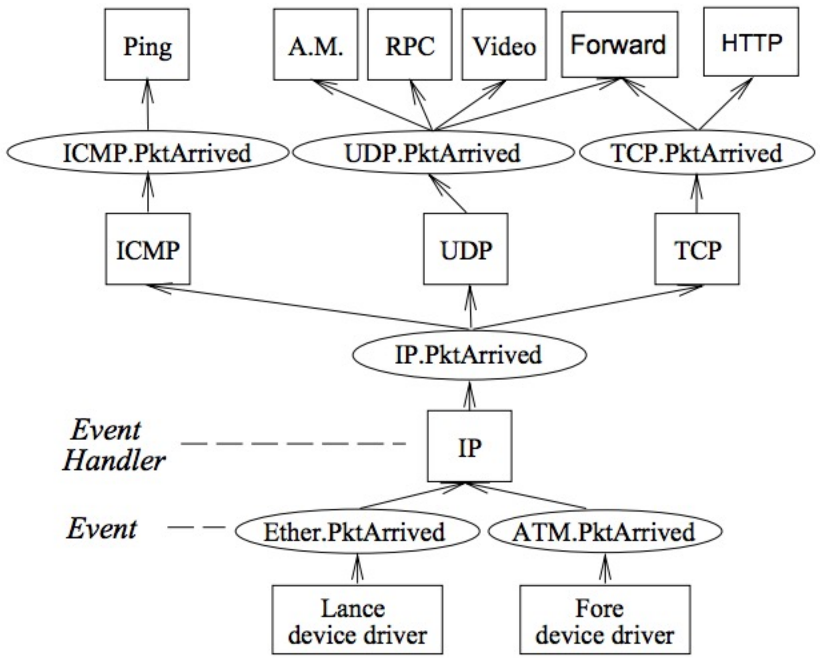



Figure 5: *This figure shows a protocol stack that routes incoming network packets to application-specific endpoints within the kernel. Ovals represent events raised to route control to handlers, which are represented by boxes. Handlers implement the protocol corresponding to their label.*

- Direct transfer from network to frame buffer
- Support of active networks
- In kernel handling of HTTP requests
- Support of Remote Procedure Call (RPC)
- Pre-cursor to packet filters!

# Default Core services in SPIN

```
INTERFACE PhysAddr;

TYPE T <: REFANY; (* PhysAddr.T is opaque *)

PROCEDURE Allocate(size: Size; attrib: Attrib): T;
(* Allocate some physical memory with
   particular attributes. *)

PROCEDURE Deallocate(p: T);

PROCEDURE Reclaim(candidate: T): T;
(* Request to reclaim a candidate page.
   Clients may handle this event to
   nominate alternative candidates. *)

END PhysAddr.
```

```
INTERFACE VirtAddr;

TYPE T <: REFANY; (* VirtAddr.T is opaque *)

PROCEDURE Allocate(size: Size; attrib: Attrib): T;
PROCEDURE Deallocate(v: T);
END VirtAddr.
```

```
INTERFACE Translation;
IMPORT PhysAddr, VirtAddr;

TYPE T <: REFANY;  (* Translation.T is opaque *)

PROCEDURE Create(): T;
PROCEDURE Destroy(context: T);
(* Create or destroy an addressing context *)

PROCEDURE AddMapping(context: T; v: VirtAddr.T;
          p: PhysAddr.T; prot: Protection);
(* Add [v,p] into the named translation context
   with the specified protection. *)

PROCEDURE RemoveMapping(context: T; v: VirtAddr.T);

PROCEDURE ExamineMapping(context: T;
          v: VirtAddr.T): Protection;

(* A few events raised during *)
(* illegal translations *)
PROCEDURE PageNotPresent(v: T);
PROCEDURE BadAddress(v: T);
PROCEDURE ProtectionFault(v: T);

END Translation.
```

Figure 3: *The interfaces for managing physical addresses, virtual addresses, and translations.*

- Page fault, access fault, bad address

# CPU Scheduling

- Spin
  - Se
- Eve
  - Bl
- Spin
  - Int age

```
INTERFACE Strand;

TYPE T <: REFANY;   (* Strand.T is opaque *)

PROCEDURE Block(s:T);
(* Signal to a scheduler that s is not runnable. *)

PROCEDURE Unblock(s: T);
(* Signal to a scheduler that s is runnable. *)

PROCEDURE Checkpoint(s: T);
(* Signal that s is being descheduled and that it
   should save any processor state required for
   subsequent rescheduling. *)

PROCEDURE Resume(s: T);
(* Signal that s is being placed on a processor and
   that it should reestablish any state saved during
   a prior call to Checkpoint. *)

END Strand.
```

Figure 4: *The Strand Interface. This interface describes the scheduling events affecting control flow that can be raised within the kernel. Application-specific schedulers and thread packages install handlers on these events, which are raised on behalf of particular strands. A trusted thread package and scheduler provide default implementations of these operations, and ensure that extensions do not install handlers on strands for which they do not possess a capability.*

# Experiments

- Don’t worry, I wont go through them
- In the OS community, you have to demonstrate what you are proposing
  - They built SPIN, extensions and applications that use them
  - Microbenchmarks to evaluate individual mechanisms
  - Focus on performance and size
    - Reasonable size, and substantial performance advantages even relative to a mature monolithic kernel

# Conclusions

- Extensibility, protection and performance
- Extensibility and protection provided by language/compiler features and run-time checks
  - Instead of hardware address spaces
  - …which gives us performance—no border crossing
- Who are we trusting? Consider application and Spin
- How does this compare to Exo-kernel?